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Da cooperação entre Max-Planck-Institut für Limnologie, Arbeitsgruppe Tropenökologie, Plön, Alemanha Oc., e Instituto Nacional de Pesquisas da Amazônia, Manaus – Amazonas, Brasil

## Seasonal variation in the major cation (Na, K, Mg, and Ca) content of the water of Lago Camaleão, an Amazonian floodplain-lake near Manaus, Brazil

by

Karin Furch, Wolfgang J. Junk, Johannes Dieterich, Norbert Kochert

Max-Planck-Institute for Limnology, Working group "Tropical Ecology", W.-Germany

### Introduction

Lakes, situated in the Amazon floodplain (várzea), are shallow bodies of water, annually filled during the period of rising water by river water, which, with a fall in water level, partially flows back into the river. Within a limnological classification these lakes may be placed midway between rivers (open systems) and lakes (closed systems) (JUNK 1980; JUNK and FURCH in press).

As a result of this periodic water exchange the chemistry of the várzea lake water is markedly affected by that of the river water:

directly through the periodical supply of soluble substances in the river water,  
indirectly by the supply of particulate inorganic matter which form the alluvium and thereby the lake sediments.

Studies about the seasonal changes in pH and specific conductance (JUNK 1973; REISS 1976) as well as about the concentration of major ions and nutrients in the water of different várzea lakes (SCHMIDT 1972a, 1973; FURCH 1982) have however shown that:

- a. the water quality of the várzea lakes can differ considerably from that of the river;
- b. várzea lakes can differ considerably from one another chemically;
- c. within a várzea lake the same pattern in electrolyte content is rarely shown in different years (FURCH unpubl.).



In addition to the particular hydrological conditions, the most important factors affecting the complex chemistry of a várzea lake relate to affluents of different chemical composition which, in addition to the Amazon water, flow into the lake. The várzea borders on the terra firme, a higher lying, nonflooded rainforest region. Its soils and waters can be distinguished from those of the várzea by their extreme paucity of electrolytes and nutrients, (FITTKAU 1964, 1967, 1971; KLINGE and OHLE 1964; SIOLI 1968; SCHMIDT 1972b; IRION and FÖRSTNER 1975; FURCH 1976; FURCH and KLINGE 1978; FURCH and JUNK 1980; FURCH et al. 1982; FURCH in press). The smaller the distance between a várzea lake and the terra firme, the stronger is the influence of the terra firme water on the lake water, i. e. the greater the dilution effect of the extremely poor water on the relatively electrolyte-rich lake water. Mixing pattern is very complex because most of the inflowing terra firme water is dependent on local rainfall, and not correlated temporally with the inflow of river water into the lake basin. Moreover, even with a reduced inflow rate, the dilution effect of the terra firme water is particularly great if the volume of the lake is small, as it happens in the low water phase (FURCH 1982).

Furthermore a series of internal lake processes, e. g. the development and decomposition of primary producers, and resuspension processes of the lake sediments play decisive roles. The nutrient and element content of a várzea lake is often attributable to the aquatic and semi-aquatic macrophytes whose primary production and biomass/unit area far exceed that of the phytoplankton. Uptake and release of large quantities of nutrients during macrophyte growth and decomposition in the terrestrial and aquatic phase have been already reported (HOWARD-WILLIAMS and JUNK 1976, 1977; JUNK 1982, 1983). Enrichment of the water by leaching of the shores and ion-exchange processes in the lake sediments during the low water period (BRAUN 1952; JUNK 1973; SCHMIDT 1973; REISS 1976) strongly influence the chemistry of many várzea lakes. As a result of the periodic switch between aquatic and terrestrial phases, the enrichment and depletion processes mediated by the aquatic and semi-aquatic macrophytes are not clearly separable from the exchange processes in the sediment. Overlaps are in rule rather than the exception so that it is extremely difficult to measure quantitatively the influences on the water chemistry.

Investigations about the seasonal variation in water chemistry of one of the várzea lakes, Lago Camaleão on Ilha de Marchantaria, are part of a recently initiated ecosystem study (KLINGE 1982), concentrated on this island in the Rio Solimões. The first results on the seasonal changes in concentrations of major cations in the lake and river water will be reported in this paper.

## Materials and Methods

### Study area

The várzea island Ilha de Marchantaria lies about 15 km upstream of Manaus in the Rio Solimões (Amazonas, above the mouth of the Rio Negro). During medium water level (Oct./Nov.) it covers an area of about 25 km<sup>2</sup>, while during highwater (May - July), on average 10 m above low water level, the island is usually almost entirely flooded (IRION et al. 1983). The Lago Camaleão basin is formed by an arrowly elongated swale along the southern edge of the island. It is exceptionally flat with the result

that the area covered by the lake changes very quickly in extension depending on the water level fluctuations. At times of relatively low water level (6 - 7 m below peak flood according to Manaus water gauge) the lake is sickle-shaped with a length of 7 km, a maximum width of 100 - 150 m and a maximum depth of 2 - 3 m. In the area of Lago Camaleão the lake bottom rises 0.4 - 0.5 m/km on average from north-east (the lake entrance into the river) to west, towards that end of the lake extending furthest into the island. Various depressions in the lake basin were designated as distinct lake sections (B, C, D, E, F, and G) and separately analysed (Fig. 1). For approximately 2 months during the low water period, with the exceptions of a residual water body, approx. 1/ha in area, the lake bottom was dry.

With rising water level, river water enters the lake from the north-east, distal to the current, and fills up the lake sections B, C and D relatively quickly. The rise in land level from B to D is barely discernible; because of their higher location, river water reaches the lake sections E, F, and G later, when the river level rises further. The supply of chemically different waters from the terra firme is excluded by the position of this lake on an island in the Rio Solimões.

## Sampling and analysis

Water samples from the surface of the different lake sections were taken at monthly intervals from Nov. 1980 to Nov. 1981. When water depth exceeded 2 m, samples near the bottom were taken as well. The samples were membrane-filtered (0.45 µm pore size, cellulose nitrate filter, Sartorius), acidified with 2 ml HCl/l (ultrapure HCl, Merck) and sent to Plön for further analysis. The major ions, Na, K, Mg and Ca were measured in an atomic absorption spectrophotometer (AAS 300, Perkin & Elmer) with an air-acetylene flame and a hydrochloric acid filtrate. (For further comments on these analysis see FURCH 1982).

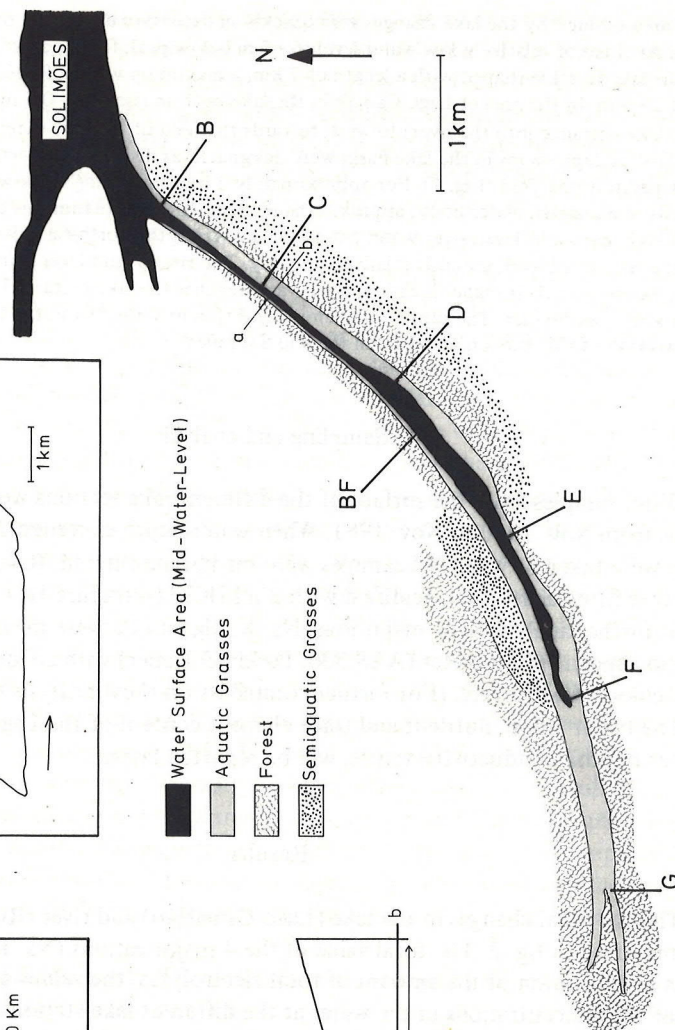
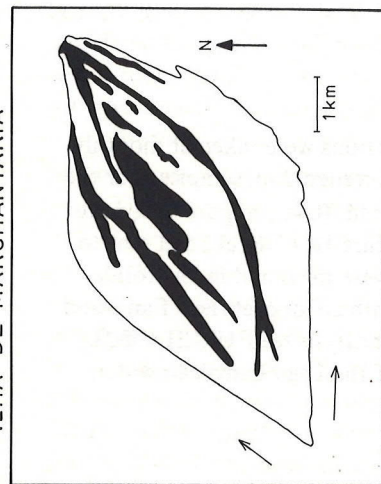
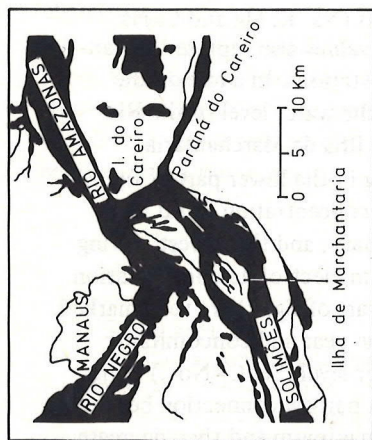
The major anion, nutrient and trace element content of the Lago Camaleão water, as well as pH and conductivity values, will be reported later.

## Results

The chemical changes in the lake (Lago Camaleão) and river (Rio Solimões) water are summarized in fig. 2. The total value of the 4 major cations (Na, K, Mg and Ca) is given as an indication of the amount of total electrolytes; the values also represent mean-values of the concentrations in the water at the different lake stations. In addition the rainfall (at Manaus, and after May 1981 in the lake area) and the water level of the Rio Negro, are given as measures of the water level changes on the Ilha de Marchantaria.

Changes in electrolyte content of the river (dark shading in the lower part of fig. 2) throughout the year are only slightly discernible. The highest concentration (17.0 mg major cations/l) is observed with increasing water level in January, and the lowest, during the high water period in August. In contrast, the fluctuations in electrolyte concentration in the lake water (grey shaded area of the curve in the lower part of fig. 2) are very marked. More than 10-fold differences are observed in the course of the year and concomitant dependance on water level is obvious. At the time of low water level (Sept. - Nov.) there is only a small volume of water in the lake, and there is only a narrow connection between the lake and river. During this period concentrations reach a maximum and then decrease when with rising water level fresh and relatively electrolyte-poor river water enters the lake.





Water Surface Area (Mid-Water-Level)  
 Aquatic Grasses  
 Forest  
 Semiaquatic Grasses

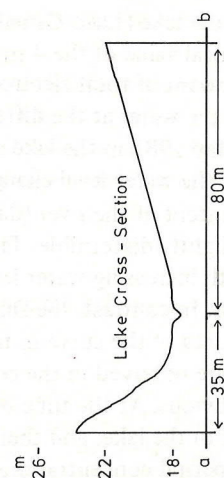


Fig. 1:  
 Sketch maps of the várzea island (Ilha de Marchantaria) and the várzea lake (Lago Camaleão).  
 The letters B, C, D, E, F, and G represent the separately investigated lake sections.

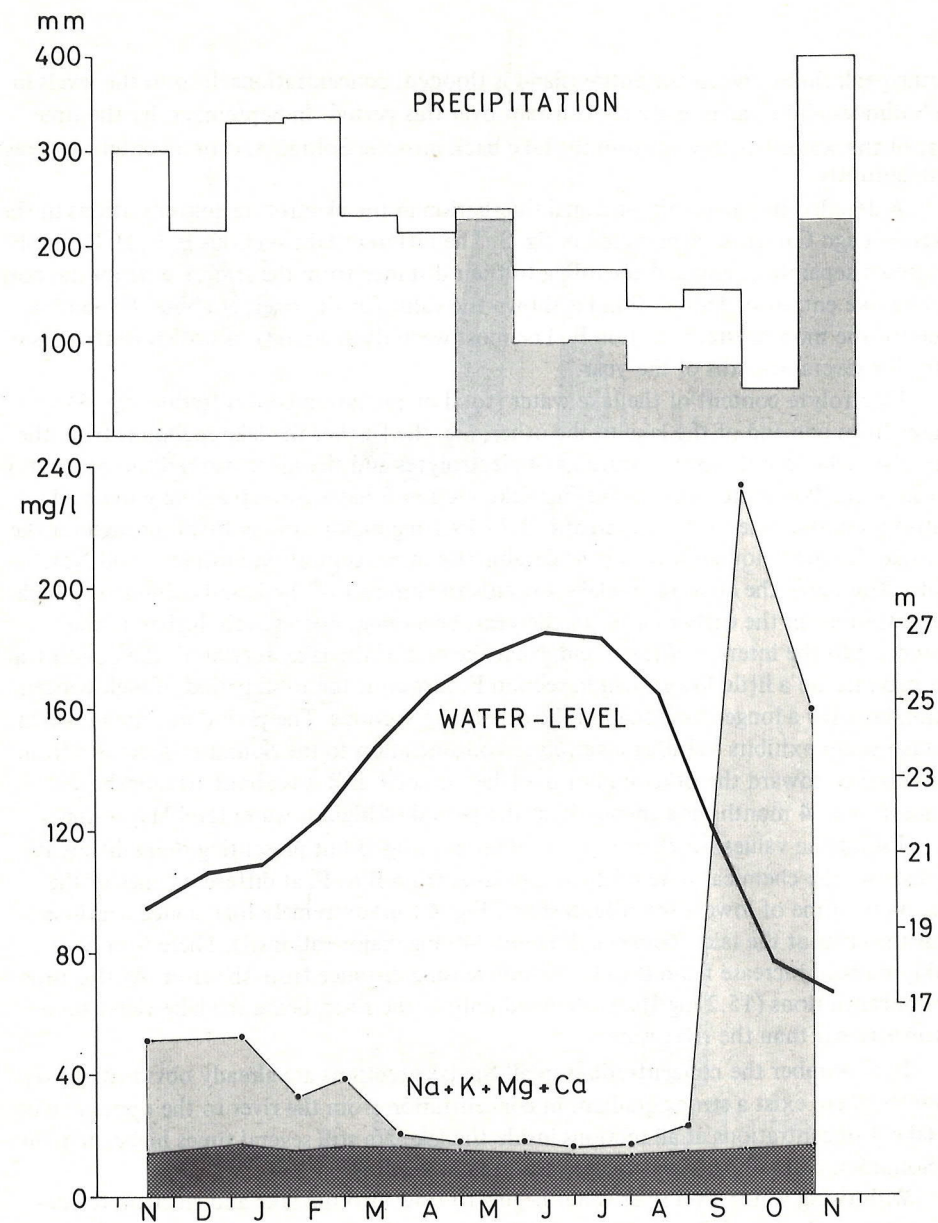


Fig. 2:  
 Precipitation near Manaus (solid line) and in the lake area (grey shading), water level fluctuation of the Rio Negro at Manaus and the changes in the major cation content (sum of Na, K, Mg and Ca) in the water of the Lago Camaleão (grey shading) and the Rio Solimões (dark shading) during the period of investigation, Nov. 1980 to Nov. 1981 (Precipitation data M. N. Goes-Ribeiro, INPA, Manaus, and Adis unpubl., water level data: Capitania dos Portos, Manaus).



During peak floods, when the entire island is flooded, concentrations drop to the levels in the Solimões and remain relatively constant over this period. In September, by the time most of the water has flowed from the lake back into the Solimões, cation content increase again abruptly.

A detailed picture of the seasonal fluctuation in the electrolyte concentrations in the water of Lago Camaleão is provided in fig. 3. The different lake sections B, C, D, E, and F are shown separately, arranged according to their distance from the river, i. e. from the north-eastern lake entrance. Thus at 0 km is shown the value for the river, at about 4.5 km the value for the more westerly section F. The most westerly section G, is not considered as it is dry for several months of the year.

Electrolyte content of the lake water (total major cation concentration, fig. 3) increases from one end of the lake to the other, i. e. the further the lake section is from the river, the higher are the concentrations of electrolytes and the more marked the concentration maxima. While the water in the first lake section B has a correspondingly low and relatively constant electrolyte content (12.7 - 19.1 mg major cations/litre) throughout the year like the river, not showing a considerable rise in concentration until Oct. and Nov. (up to 206 mg/l), the areas of the lake towards the interior of the island exhibit very high concentrations in the early months of the year, becoming progressively higher as one advances into the interior of the island. Near the end of the lake, section F, the concentration maxima are a little lower than in section E, however, the total period of high concentration lasts for a longer time than in the other lake sections. The period of time in which the lake water exhibits a similar electrolyte concentration to the Solimões decreases from lake entrance toward the other end of the lake; in section B it is about 10 months, in section F only 4 months and then only at the period of highest water level May - Aug.

Taking the values for electrolyte content as in fig. 3 but presenting them differently, fig. 4 shows the chemical state of the entire lake, from B to F, at different times of the year. At the time of lowest water level (Oct., Fig. 4 top) extremely high concentrations occur throughout the lake (between 206 and 249 mg major cations/l). There is only a weakly marked increase from B to E, with increasing distance from the river. At this time low concentrations (15.2 mg/l) are observed only in the river, being the lake water up to 15 times richer than the river water.

In November the concentrations in all the lake sections are already obviously lower. However, there exist a strong gradient in concentration from the river to the upper end of the lake. Concentrations at all sections inside the lake are still several times higher than in the Solimões, being the highest values measured at section E.

With rising water level river water begins to flow into the lake and electrolyte concentrations in the lake fall concomitantly. In January the river water has advanced into the first lake section B, diluting the water to the same electrolyte concentration as the river, or exchanging it. In the following months the river water advances further into the island, clearly reflected by the fall in electrolyte concentrations to the concentration level of the Solimões at the other lake sections. In April the last section F can still be distinguished as it maintains a somewhat higher concentration, but after May only minor differences between the different lake sections, and between lake and river can be noted. At this time river water flows in from the uppermost (westerly) point of the island and the lake can no longer be distinguished from its neighbouring water bodies.

Na + K + Mg + Ca

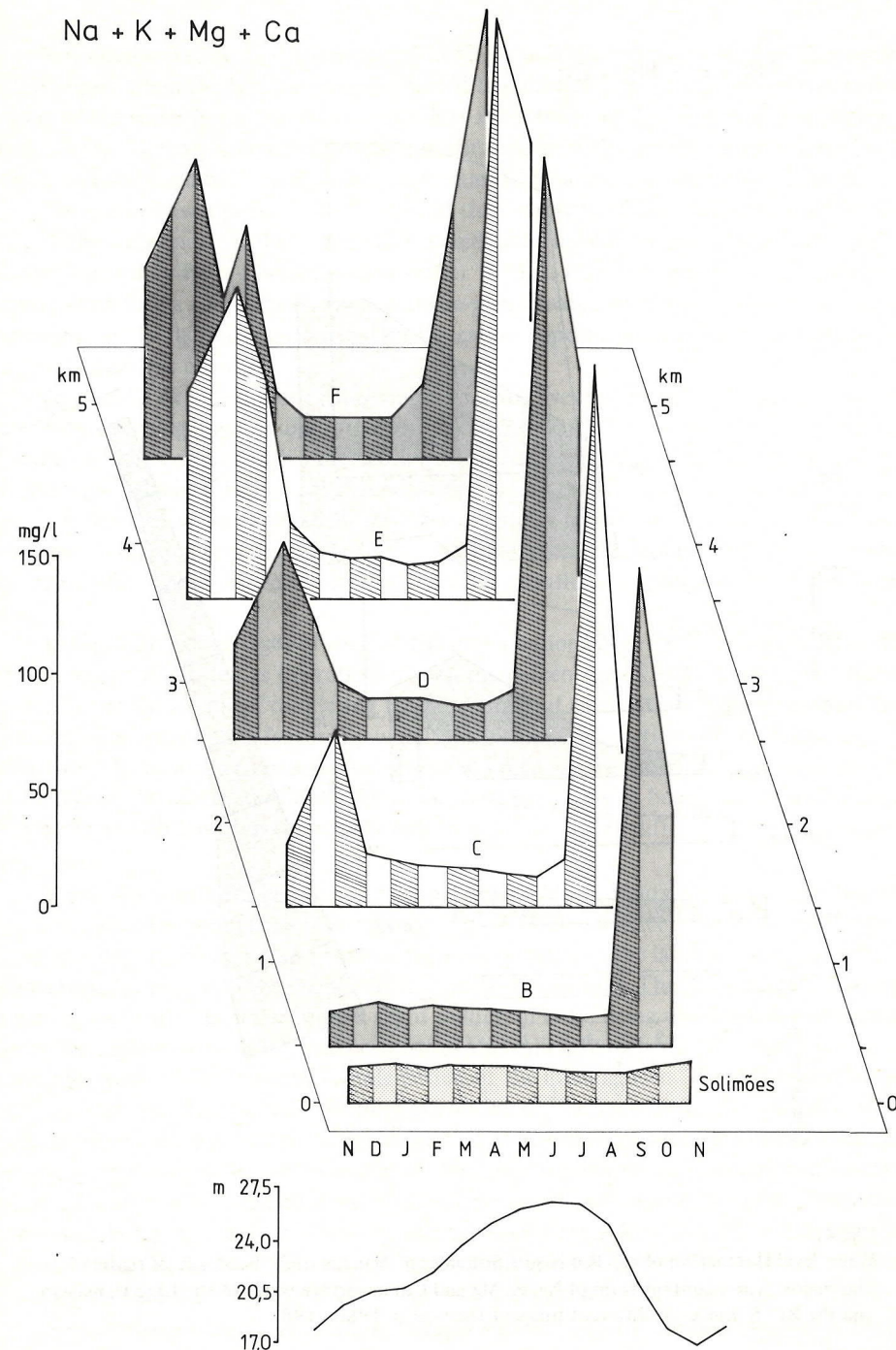


Fig. 3: Fluctuation in water level of the Rio Negro/Solimões at Manaus (lower part of figure), changes in major cation content (sum of Na, K, Mg and Ca) in surface river water (Rio Solimões) and in surface water of different lake sections of the Lago Camaleão during the investigation period, Nov. 1980 - Nov. 1981.



Na + K + Mg + Ca

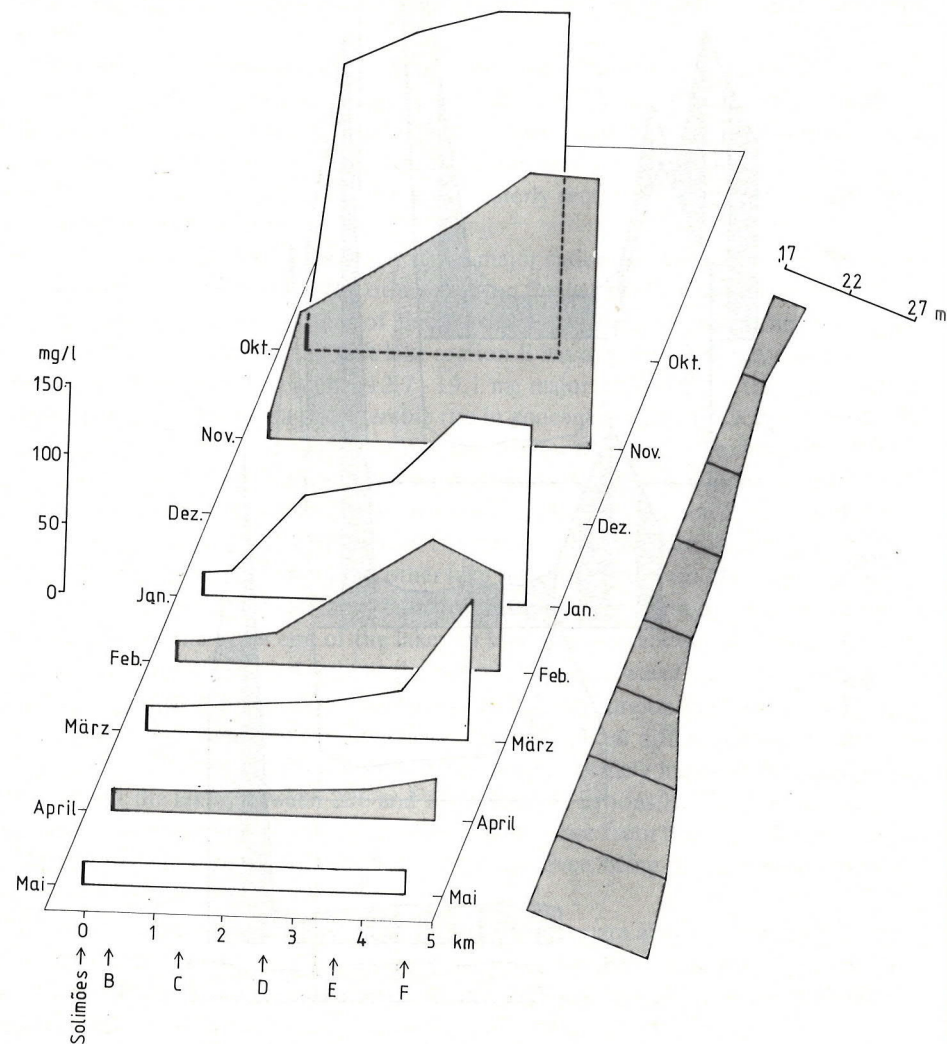


Fig. 4:  
Water level fluctuation of the Rio Negro/Solimões at Manaus (right hand side of figure) and major cation content (sum of Na, K, Mg and Ca) in surface water of the Lago Camaleão and the Rio Solimões at different times of the year in 1980 - 1981.

The chemical state of the lake found in May persists almost unaltered until August. In September when the lake becomes separated from the river again the content of major cations of the water in the last lake section F is again twice as high as in the river (as for April, see fig. 4). Only a month later the concentrations in all the lake sections have increased to their maxima, i. e. there is a more than 10-fold increase within one month.

The results given in figs. 2 to 4 relate to the chemistry of the lake surface water only. In fig. 5 the water near the bottom is also considered. However, water depth in the lake was sufficient only from January to September 1981 to allow sampling at 2 m depth or deeper. Therefore a complete set for the entire year can not be given. Instead of absolute concentrations in mg/l, the ratio between the cation concentrations of the lake water and the river water was chosen.

As is to be expected, with rising water level the average ion concentration of the lake water falls, reaching a minimum in the period of high water. It can also be seen that at no time during the period of high water does the ion concentration in the lake drop to that of the river (grey shading in the background of fig. 5) i. e. the lake water is always richer in ions than the river water, even when the river overflows the island and displaces the richer lake water. This applies particularly to the deep water which is considerably richer in ions than the surface water, especially in the first three months of the high water period (April - June).

In fig. 6 the percentages of each of the major cations have been calculated from the total amount and plotted as the ratio between the percentage of each cation in the lake water and the river water. Considering the percentage of each cation in the river water as 1, the calculation enables the factors by which the element proportions of the lake water differ from those of the river water to be directly read at any chosen time. In this way it can be seen if the lake water differs from the river water only in being more concentrated (cf. Fig. 5), or if it has been chemically modified, i. e. it shows differences in the element proportions.

There are clear differences in the proportion of the elements present in the lake and the river water throughout the investigation period. With one exception, the percentage Na in the lake water is always lower than in the river water, i. e. the lake water is relatively Na impoverished, more so in the deeper layers than at the surface. The percentage Ca is very similar in lake and river water, only a slight reduction in Ca being observed near the bottom, during the highest water level. The percentage Mg is slightly higher in the lake water than in the river water throughout the whole period of the investigation. The difference between surface water and water near the bottom is only small. The most strongly marked chemical modification of the lake water occurs in relation to K which shows large fluctuations during the course of the year. At the beginning of the rise in water level in February both surface water and water near the bottom are relatively poor in K; subsequently rapid K enrichment is observed, reaching a peak in April. At this time percentage K is 2 to 2 1/2 times greater in the lake than in the river. During the high water period water near the bottom can also be distinguished from the surface water because of its greater K enrichment.

Summarizing we may say that by comparison with the river water the lake water not only shows a higher total ion concentration, in itself an important measurement, but also markedly modified element proportions, indicating extensive chemical modifications of the water inside the lake.



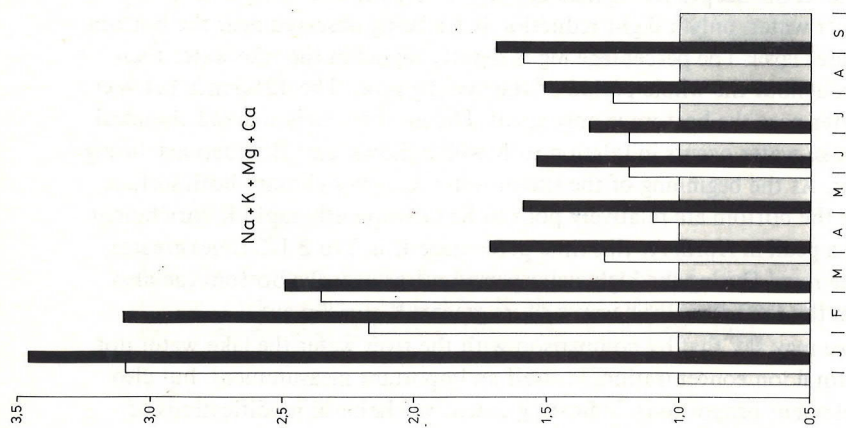


Fig. 5: Average values for the major cation content (sum of Na, K, Mg and Ca) in the surface water (white columns) and in water near the bottom (black columns) of the Lago Camaleão, presented as the ratio of the average content in lake water to that in river water (Rio Solimões). The Rio Solimões (ratio of 1) is shown as grey shading in the background.

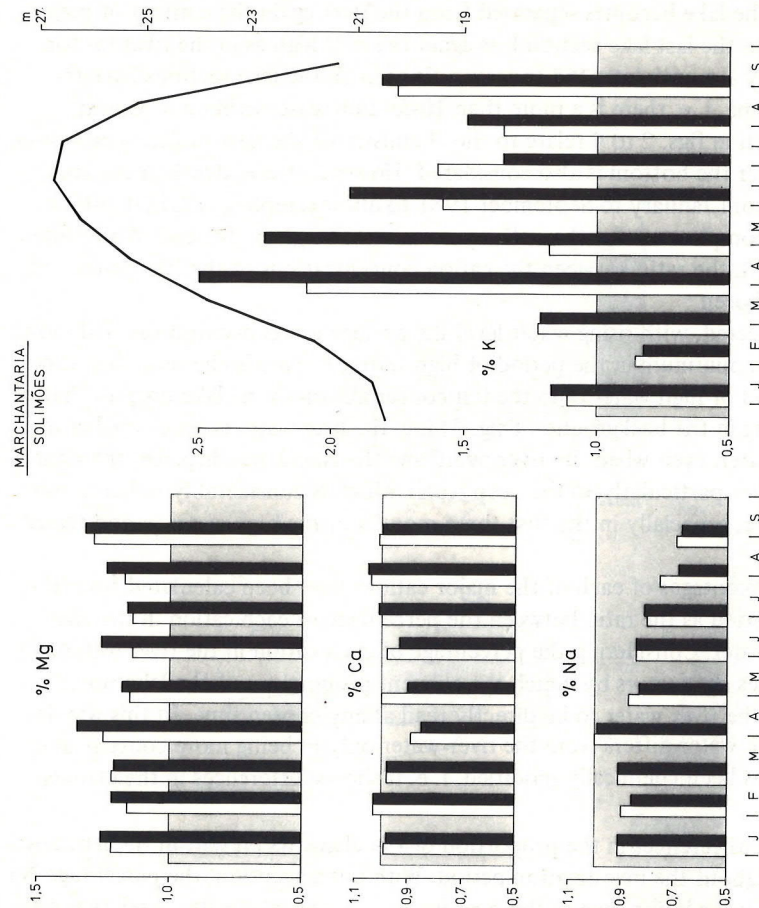


Fig. 6: Percentage of each of the major cations (Na, K, Mg and Ca) calculated from the sum of the elements in surface water (white columns) and in the water near the bottom (black columns) of the Lago Camaleão presented as the ratio of the percentage of each cation in lake water to that in the river water (Rio Solimões). The Rio Solimões (ratio of 1) is shown as grey shading in the background. At figure 6d the water level fluctuations of the Rio Negro/Solimões (linear curve) are shown. Year of investigation: 1981.

Because of its position on an island, Lago Camaleão is under the influence of the relatively electrolyte-rich white water (SIOLI 1950) of the Rio Solimões. It is not additionally fed by electrolyte-poor water from terra firme creeks, as for instance Lago do Castanho (SCHMIDT 1972a, 1973) and Lago Calado (FURCH 1982). These two lakes are so-called mixed-water lakes (FITTKAU et al. 1975; REISS 1976) to different extents under the influence of terra firme waters. Considerable fluctuations in their ion content are mostly due to dilution processes which result in a drop of ion content far below the level in the Solimões (FURCH 1982).

The assumption that the high ion content of the Lago Camaleão is chiefly mediated by the lack of terra firme water may therefore be more likely. However investigation about the seasonal changes in the electrolyte content of Lago Muratú, another várzea island lake (REISS 1976), and Lago Jacaretinga, a várzea lake in the river floodplain but far from the terra firme and barely affected by terra firme water (FURCH unpubl.), show that isolation from the terra firme cannot be the only reason for the high ion content of the Lago Camaleão. In lakes influenced only by white water, the ion content is indeed often higher than in the river itself (FURCH 1976, in press), but still extraordinarily low in comparison with the extremely high content in Lago Camaleão. Even unusually high conductivity values observed in várzea lakes (JUNK 1973) do not exceed those of Lago Camaleão. Since the sediments, as well as the water in the lakes originate from the Rio Solimões (the comparatively low ion input from rainwater is not considered here) the increase in electrolyte concentration of the várzea lake water, above that of the river, must result from internal lake processes. In this respect concentration due to evaporation and enrichment resulting from the accumulation of substances in the system, must be differentiated.

The increase in electrolytes by concentration or enrichment can be distinguished from one another by the element proportions. During concentration of the water by evaporation the electrolyte content increase iso-proportionally, i. e. the proportion of the ions to one another remains constant. Low rain fall, high air temperature and the extremely low lake-depth to lake-surface area ratio favour evaporation during dry season. Therefore, the extremely high ion content encountered in the Lago Camaleão water during the low water period (Figs. 2 - 4) may be partly due to evaporation of the water.

With increased evaporation chemical precipitation can occur. In white water of the Rio Solimões, belonging to the carbonate-water group (FURCH et al. 1982, FURCH in press), precipitation of calcium carbonate may lead to a reduction in percentage Ca (of the total major cations). However, the percentage of Ca in the Lago Camaleão water fluctuates only slightly indicating that precipitation is not occurring.

Evaporation alone cannot account for the high ion content, since the strongly modified relative proportions of the elements implicate the occurrence of enrichment processes during the investigation period. Enrichment of the water leads to a shift in the element proportions if the ionic contribution to the water comes from substances with a different chemical composition in comparison with the river water. This applies to the várzea sediment (IRION and FÖRSTNER 1975) as well as to aquatic macrophytes (HOWARD-WILLIAMS and JUNK 1977). From our earlier observations the enrichment processes,



particularly the release of elements during mineralization of dead plant material, but also that due to resuspension of sediments, at low water affect strongly the electrolyte budget of the lake. The strong enrichment of K in the lake water additionally point to plant material as source of major cations, because aquatic macrophytes are able to accumulate major cations and principally K in considerable quantities (HOWARD-WILLIAMS and JUNK 1977). Furthermore the enrichment in K is particularly large in the water near the bottom at the time of rising water level, when the macrophytes which during dry season grew on the exposed lake bottom are flooded, die and are very rapidly decomposed (HOWARD-WILLIAMS and JUNK 1976).

Várzea lakes which are under basically the same chemical influences (similar or almost identical sediments, identical inflowing river water quality) nevertheless present great differences in electrolyte content. This is shown by observations on another lake on the Ilha de Marchantaria. This lake, situated in the central part of the island (cf. Fig. 1) has at the time of low water (Nov. 1980) a several fold lower electrolyte concentration than Lago Camaleão (FURCH unpubl.) notwithstanding its immediate proximity. It is suggested that these differences are primarily caused by the different conditions for macrophyte growth. Várzea lakes with exceptionally abundant macrophyte growth like Lago Camaleão have water which is very much richer in electrolytes than lakes with a small macrophyte vegetation.

The development of an abundant aquatic and terrestrial herbaceous vegetation is dependant on the morphology of the lake basin, current patterns, as the lake is filled by water from the river and as water flows from the lake into the river, and associated sedimentation conditions in lake and river for the particulate fraction. In this context the relationship between the exposed lake area with its remaining macrophyte biomass and the residual water body area is decisive. The greater the quantity of organic material per unit area drying on the exposed beaches the greater the quantity of electrolytes leached by the rain and transported to the remaining water body ("Uferfaktor" BRAUN 1952). The enrichment of the residual water body is inversely proportional to its size. In the Lago Camaleão the ratio between exposed lake bottom and residual water body is about 100 : 1 but in the central lake it is only about 2 : 1. Furthermore growth of a large amount of terrestrial herbaceous plants on the dry sediment, which with rising water level become decomposed, leads to an increase in the electrolyte content of the lake water. This accounts for the particularly high rise in the electrolyte content of the Lago Camaleão close to the ground. A quantitative account of the nutrient cycle will be possible once a detailed estimate of the nutrients in the vegetation has been made.

### Summary

Changes in the major cation content (Na, K, Mg and Ca) of the Lago Camaleão, one of the várzea lakes on an island in the Rio Solimões/Amazonas near Manaus were followed during one year. Comparative changes were also followed in the Rio Solimões. Changes in the electrolyte content of the lake water, presented as total major cation content, are extremely great during the period of investigation. Nov. 1980 to Nov. 1981, and show a pronounced annual periodicity. During the low water period (Oct. 1981) the ion concentration reached its maximum and was more than 15 times higher than in the river at the same time. With rising water level, in flow of comparatively electrolyte poor water from the river and simultaneously increasing rain fall dilute the water in the lake. In the following months there is a relatively

sudden reduction of the electrolyte content of the lake water. By the time of high water the levels have fallen almost to those of the river. With falling water level concentrations of major cations at first increase very slowly followed by an abrupt change within one month, from approx. 20 mg major cations/l to approx. 230 mg/l. Investigation of different lake sections showed that the electrolyte content is not uniform throughout the lake. Concentrations rise from the lake entrance to the inner part of the lake, so that the lake sections distant from the river are up to fifteen times as rich in electrolytes as the river itself.

The changes in total ion content are accompanied by marked changes in the chemical composition of the lake water during the year, i. e. in the relative proportions of each of the four elements (Na, K, Mg and Ca). Greatest changes are shown by the element K. The deeper water of the lake during the high water period is richer in K probably due to the release of elements from the decomposition of K-rich terrestrial and aquatic macrophytes. The uptake of large quantities of nutrients from the system for the growth of macrophytic vegetation, the accumulation of nutrients in macrophytes and sediment, and the release of these nutrients during decomposition and resuspension are among the most important factors contributing to the electrolyte budget in the Lago Camaleão.

### Resumo

Durante um ano foram acompanhados as modificações nas concentrações dos cations principais (Na, K, Mg e Ca) no Lago Camaleão, lago de várzea numa ilha no Rio Solimões/Amazonas perto de Manaus. Estudos comparativos foram realizados também no Rio Solimões. Modificações no conteúdo dos eletrólitos na água do lago apresentados pela quantia total dos cations principais, foram extremamente grandes durante o período estudado de Novembro 1980 até Novembro 1981 e mostraram uma periodicidade pronunciada. Durante o período de água baixa (Oct. 1981) a concentração dos cations chegou ao máximo e estava mais que 15 vezes maior que a concentração na água do rio ao mesmo tempo. Durante a enchente, a entrada de água do rio relativamente pobre em eletrólitos e o aumento das chuvas diluíram a água no lago. Nos meses seguintes a concentração dos eletrólitos na água do lago foi reduzida rapidamente.

Durante o período da enchente máxima, as concentrações chegaram quase aos níveis da água do próprio rio. Quando a água baixou, as concentrações dos cations principais aumentaram no começo somente devagar, mostrando de repente em um só mês um aumento drástico, de cerca de 20 mg/l para cerca de 230 mg/l cations principais. Estudos em diferentes áreas do lago mostraram, que a concentração de íons no lago não foi uniforme. A concentração aumentou da boca do lago para as áreas interiores, sendo as áreas mais distantes do rio até 15 vezes mais ricas em eletrólitos de que o próprio rio.

As mudanças nas concentrações totais foram acompanhadas por mudanças consideráveis em respeito à composição química da água durante o ano, quer dizer nas proporções relativas de cada um dos quatro elementos (Na, K, Mg e Ca). As maiores mudanças mostrou o K. A água perto do fundo do lago foi mais rica em K durante a cheia, provavelmente por causa da liberação de elementos através da decomposição de macrófitas terrestres e aquáticas, ricas em K. A absorção de grandes quantidades de nutrientes do sistema pelas macrófitas aquáticas, a acumulação desses nutrientes na matéria vegetal e nos sedimentos e a liberação dos nutrientes durante a decomposição e resuspensão, são alguns dos factores principais influenciando o balanço dos eletrólitos no Lago Camaleão.

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Authors' addresses:

Dr. Karin Furch  
Dr. Wolfgang J. Junk  
Johannes Dieterich  
Norbert Kochert  
Max-Planck-Institut für Limnologie  
Arbeitsgruppe Tropenökologie  
Postfach 165  
D - 2320 Plön/Holstein  
West Germany

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